Fall 12-2011

A GIS Approach for Estimating Optimal Sites for Grid-Connected Photovoltaic (PV) Cells in Nebraska

Tomotoshi Funabashi
University of Nebraska-Lincoln

A GIS Approach for Estimating Optimal Sites for Grid-Connected Photovoltaic (PV) Cells in Nebraska

by

Tomotoshi Funabashi

AN UNDERGRADUATE THESIS

Presented to the Faculty of
The Environmental Studies Program at the University of Nebraska - Lincoln
In Partial Fulfillment of Requirements
For the Degree of Bachelor of Science

Major: Environmental Studies, Geography, and French
Minor: Mathematics

Under the Supervision of Dr. Kenneth G Hubbard

Lincoln, Nebraska

December 2011

A GIS Approach for Estimating Optimal Sites for
Grid-Connected Photovoltaic (PV) Cells in Nebraska

Tomotoshi Funabashi, B.S.

University of Nebraska, 2011

Advisor: Dr. Kenneth G. Hubbard

Abstract

In the context of rising energy concerns and increased spotlight on solar energy, this study examines and draws attention to the state of mid potential sunlight. The purpose of this study is to estimate the optimal sites for grid-connected photovoltaic cells in Nebraska, which is ranked 13th nationally in terms of insolation potential. Five factors – insolation potential, adjacency to roads, accessibility to grid, topography, and acreage – are examined with the use of Geographic Information System (GIS). Insolation potential was quantitatively analyzed by averaging, plotting, and interpolating the 20 years of datasets recoded at 28 weather stations of High Plains Regional Climate Center (HPRCC). The other four factors are qualitatively examined by the screening criteria adopted from Environmental Protection Agency (EPA). It has been shown that weather is an important factor that controls the insolation potential, and that optimal sites found in southwestern regions of Nebraska all correspond with agricultural land, which may create the conflict over land usage between agriculture and solar energy.

Table of Contents: Page

Acknowledgement

I would like to thank Dr. Ken Hubbard for providing me the access to the Classic Online Services of High Plains Regional Climate Center as well as for providing various ideas to me as thesis advisor, Dr. David Wishart for serving as my thesis reader, Ms. Joyce Hurst and Ms. Patty Swanson for providing me the access to the 24/7 computer lab in Hardin Hall. In addition, I would like to acknowledge the assistance provided by Sara Cooper.

1. Introduction

Utility of energy, especially in electrical form, has been contributing to the development of our society with the use of polluting fossil fuels. However, it is estimated that oil can be used up in next 45 years and that natural gas will be in next 60 years (Osaka Gas 2010). The security of energy has always been a national concern for countries with scarce resources such as Japan, which has sought nuclear energy and the associated dangers of radioactive waste disposal increased by the presence of frequent earthquake activity. Today, many countries are still heavily dependent on fossil fuels and it is argued that they will soon have to find different ways to secure energy.

Since virtually all the energy on earth is derived from the sun, solar energy is one of the most expected sources for energy among other renewable energies. However, photovoltaic cells have not yet reached the efficiency to be economically feasible for places without intense insolation (incoming solar radiation), and especially without institutional incentives such as governmental subsidy for solar energy (C. Schwarz, unpublished data, 2010). There are other difficulties as well, besides the efficiency problem. The fact that there are many types of photovoltaic cells being developed make it very difficult for companies and governments to decide which types of photovoltaic panels to invest in at the moment (Ozaki 2009). In addition to this, the difficulty of siting renewable resources, including solar energy, is that the renewable resources are inflexible and often found away from the existing transmission lines.

This means that solar energy will not become economically viable without adequate transmission lines and that new transmission lines will not be invested in and established without the adequate potential amount of electricity produced by photovoltaic cells (Vajjhala 2006). Despite these difficulties, the potential significance of solar energy is enormous. The incoming solar radiation can satisfy 6000 times the world's demand, and it is said that, with the current technology, solar energy can meet the world's demand dozens of times (Johnson 2009).

Therefore, investigating the optimal deployment of solar energy has great importance to the potential application and to the spread of solar energy. In order to properly and efficiently situate the solar panels, one has to examine various factors, such as insolation potential, slope of the land, accessibility to the electrical grid, and so forth. Employment of Geographic Information System (GIS) allows simultaneous analysis of these factors. In recent years, it has become a more common practice to use GIS to investigate potential solar energy. For example, Web GIS has helped track the progress of solar installations in Boston, and ESRI's ArcGIS spatial analyst was employed to calculate the solar energy potential of building rooftops (ESRI 2008). Also, mapping the solar potential of rooftops using GIS helped promote solar energy in the city of Osnabruck, Germany (ESRI 2009). Environmental Protection Agency (EPA) uses GIS to investigate and creates maps for grid-connected utility potential solar energy as well (EPA 2010).

2. Objective

This study suggests a GIS approach to find the optimal sites to place grid-connected photovoltaic cells in Nebraska. An "optimal" site is defined as a place that maximizes the facility of establishment and maintenance of photovoltaic-cell-based utility, the potential amount of electricity generated, and the efficient transmission of the electricity.

A study has shown it is economically unfeasible to place PV cells in Lincoln, Nebraska, with the current efficiency rate and without governmental subsidies (C. Schwarz, unpublished data, 2010). Related to that, this study has its importance in terms of searching for better locations for PV cells in Nebraska other than Lincoln. It is also important because detailed GIS research has been done in the southwestern region of the United States where the potential solar energy is the highest (Mehos et. al. 2005) but not much has been studied in detail for Nebraska. Nebraska currently ranks 13th in solar power potential (NEO 2010), and therefore, is a future candidate state for solar energy. Thus, by studying the mid-potential state of Nebraska, this study aims to draw attention to the places with mid-insolation potential.

Also, EPA investigated Nebraska for potential solar energy (EPA 2010) for the purpose of reusing contaminated land (Figure 1), but it is not detailed enough for practical purposes, especially in terms of where in Nebraska one should establish utility PV cells. Thus, this GIS study is important to complement and fill the any gaps in previous research studies of the potential solar energy in Nebraska.

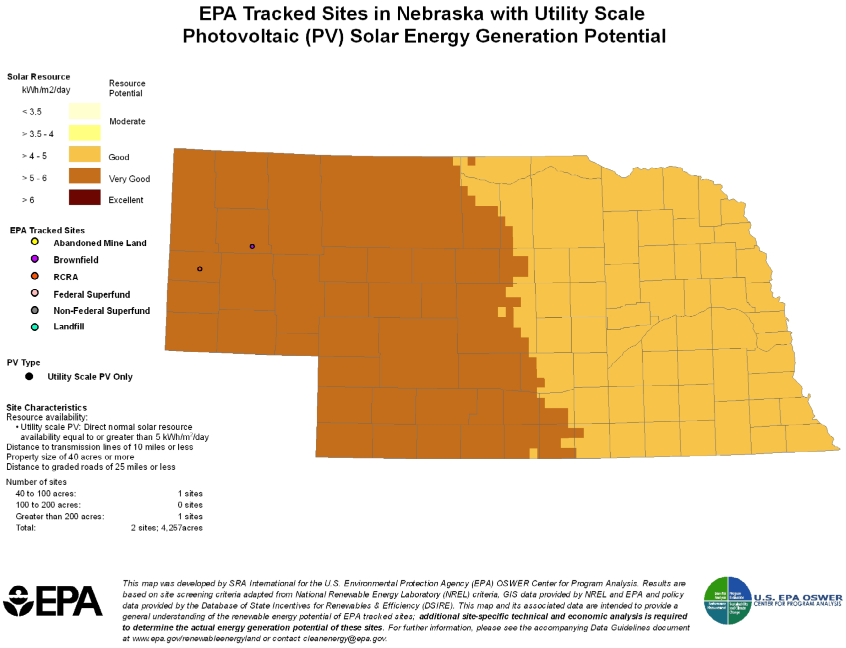


Figure 1. Nebraska is one of the 21 states investigated by the EPA for utility scale PV solar energy generation potential (Source: EPA).

3. Methods and Materials

There are principally five factors to be considered in order to determine the optimal sites for grid-connected solar utility. These five factors are – amount of insolation, road adjacency, topography, accessibility to the grid, and acreage.

The amount of incoming solar radiation is the most important factor, since this determines the amount of energy that can be converted into electricity. Road adjacency, topography, and accessibility to the grid are the three factors that determine the level of difficulty to place PV cells. The closer to the grid and road, and flatter the topography at a candidate site, the easier it is to establish grid-connected PV utility there. The closeness to the grid also means less loss of electricity when transferring electricity through transmission lines. Acreage is a geographical factor that determines the efficiency of economical benefits. The larger a candidate site is, the better for grid-connected utility of PV cells. Since this is a study focused on determining the optimal sites, all factors mentioned here are geographical, and thus, GIS is used. Non-geographical factors that will not be considered in this study are the efficiency of PV cells, the capacity of PV panels to follow the path of the sun, the cost of PV cells, and state energy portfolio. Because the amount of solar radiation is a global factor while the other factors are local, the process of this study is divided into two steps.

3.1 Quantitative Analysis

The first step, thus, involves the insolation potential. Since this is the most important factor, this is quantitatively analyzed. Datasets for the weather stations in North Dakota, South Dakota, Wyoming, Colorado, Kansas, and Nebraska are provided by the Classic Online Services of High Plains Regional Climate Center (HPRCC). For this study 28 of the approximately 70 stations in Nebraska that collect the amount of incoming solar radiation were identified and data from January 1st, 1990 to December 31st, 2009 were assembled. The amount of daily incoming solar radiation for each station is averaged over the period of the 20 years for each station. Averaged values for each station are plotted on a map of Nebraska with longitude and latitude based on World Geodetic System 1984 (WGS84), and then, interpolated using Kriging, an interpolation method suitable for meteorological phenomenon and weather observations, on ArcGIS (Figure 2).

Averaging the data in the past can be used as a mean of forecasting the potential solar energy in the future unless there is a climate change. In this study, therefore, it is hypothesized that the tendency of insolation potential does not change in the future. Averaging datasets over the period of 20 years is also reasonable because it takes out the annual climate variability and because PV cells usually take at least 10-20 years to actually start making economic profit with the institutional subsidies. The result of this first step will be used to narrow down the sites to be further studied in the second step.

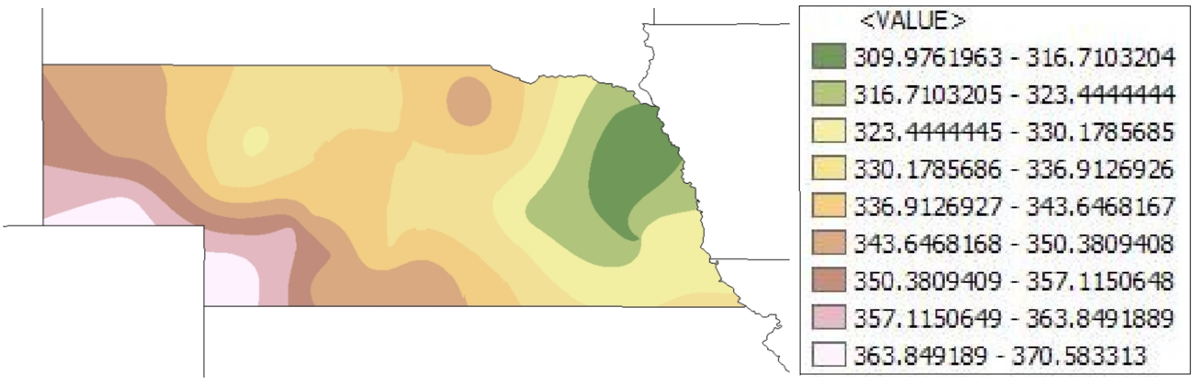


Figure 2. Preliminary result of average daily incoming solar radiation in Nebraska is shown. It is revealed that there is more potential solar energy in southwestern Nebraska than the rest of the state. The unit of the value is in langley. 1 [langley] equals to 1 [cal/cm^2] or 41868 [joules/m^2] (Source: NRCS, United States Department of Agriculture).

3.2 Qualitative Analysis

The second step is to qualitatively evaluate the remaining four factors (road adjacency, topography, accessibility to the grid, and acreage) on the area of high potential solar energy. As the preliminary result of step one indicates, the region of southwestern Nebraska has the highest amount of insolation in the state. Therefore, this region will be the area of study for this second step and raster overlay analysis, by screening of each of the four factors using ArcGIS, will provide the required information. Screening criteria are shown below (Table 1).

Factors	Requirement
Adjacency to the road	Distance to graded roads ≤25 miles
Accessibility to the grid	Distance to transmission line ≤10 miles
Topography (Slope)	Slope = 0 degree, or close to horizontal
Acreage	≥40

Table 1. Screening criteria are adapted from Data Guideline for Renewable Energy Generation Potential and State Tracked Sites Maps Produced by EPA. The topography factor was added to modify the screening criteria.

Maps for each of the four factors are prepared in raster format. Raster datasets for road adjacency and accessibility to the grid are prepared by buffering vector datasets of roads and transmission lines. A map for topography, or a map of slope, is prepared from National Elevation Model (NED) by using slope analysis. A map for acreage is prepared by neighborhood analysis after the screening by the other three criteria was performed. All the data processing from obtaining data from public resources to raster overlay analysis is indicated below (Figure 3).

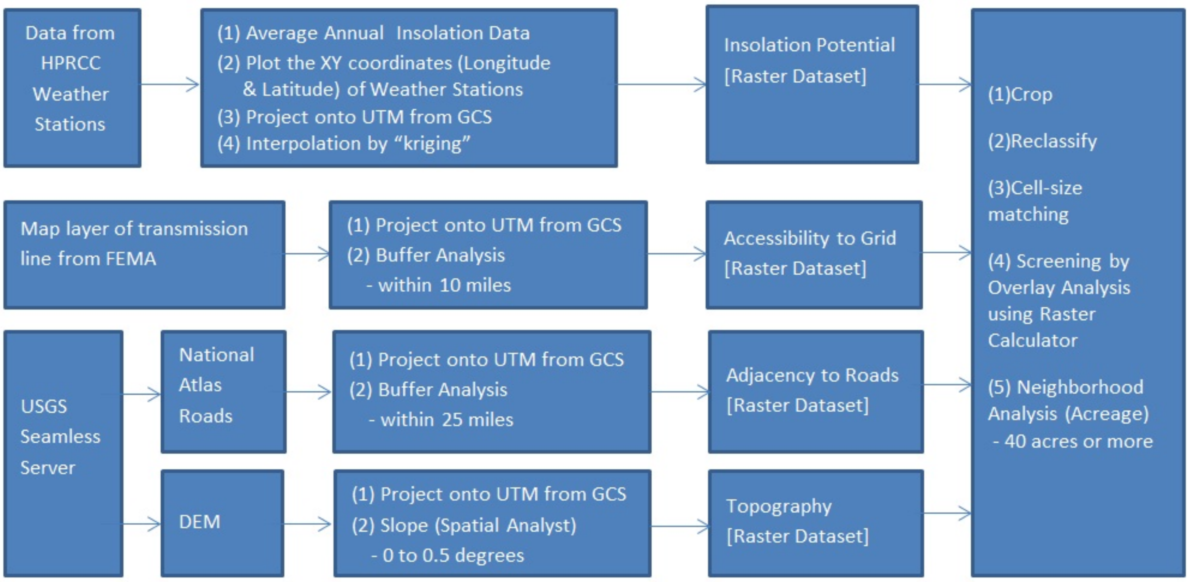


Figure 3 The overview of data processing on ArcGIS in this study is shown. All the raster datasets are projected on UTM in order to better perform Spatial Analyst tools on ArcGIS.

The last analysis is done by neighborhood analysis through which various statistics of neighboring cells that surround a single cell can be calculated in raster datasets. Neighboring cells are predefined by the shape and size of a kernel, and in this study, a 9-cell-radius circle is utilized. To approximate the acreage of optimal sites, the number of cells in the predefined kernel for each cell that satisfies all the previous screening criteria have been counted (Figure 4) and reclassified.

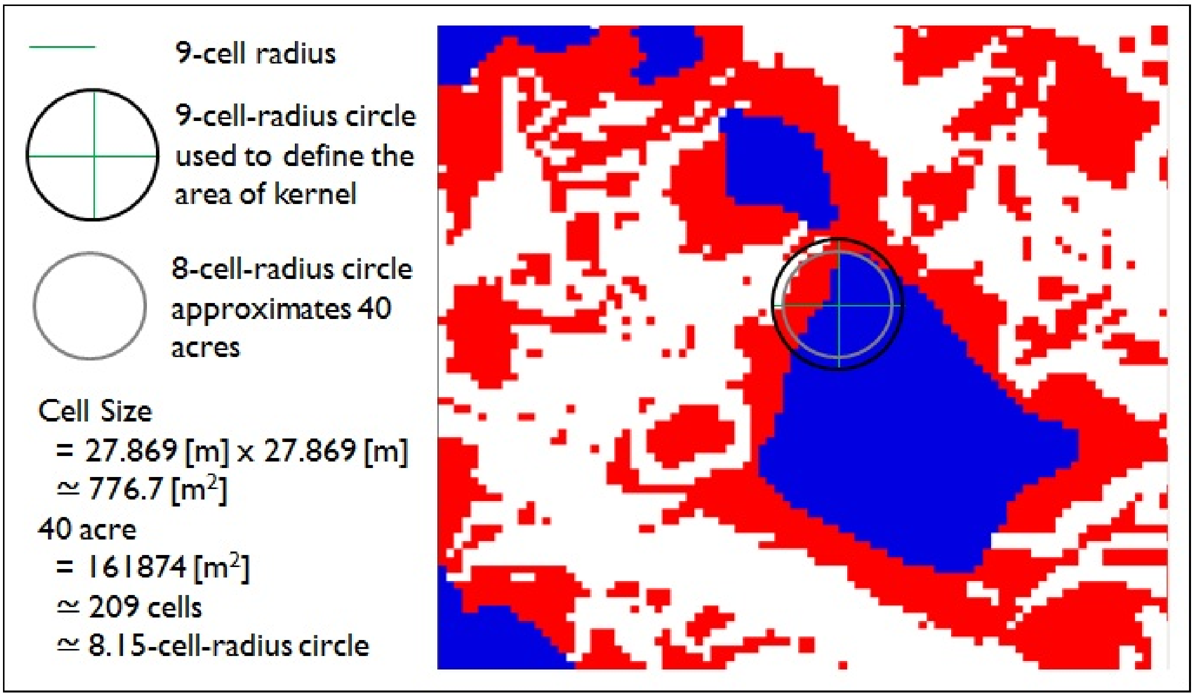


Figure 4 How neighborhood analysis is performed. The red cells meet all the criteria other than acreage (insolation, topography, adjacency to roads, and accessibility to grid). The blue cells, whose neighboring cells are more than 209 cells, approximate and highlight the cells that meet all the criteria including acreage.

3.3 Coordinate System and Projection

Many GPS units by default store coordinates as longitude/latitude with the WGS84 datum. Longitude and latitude are spherical (and thus unprojected) coordinate system called Geographic Coordinate System (GCS), which uses the decimal degrees as its measuring unit. Since this unit of measurement is not ideal for yielding accurate straight-line distance, area, or slope measurements, map layer or datasets with these coordinates will be projected onto Universal Trans Mercator (UTM) to perform spatial analyses accurately.

3.4 Data and Software

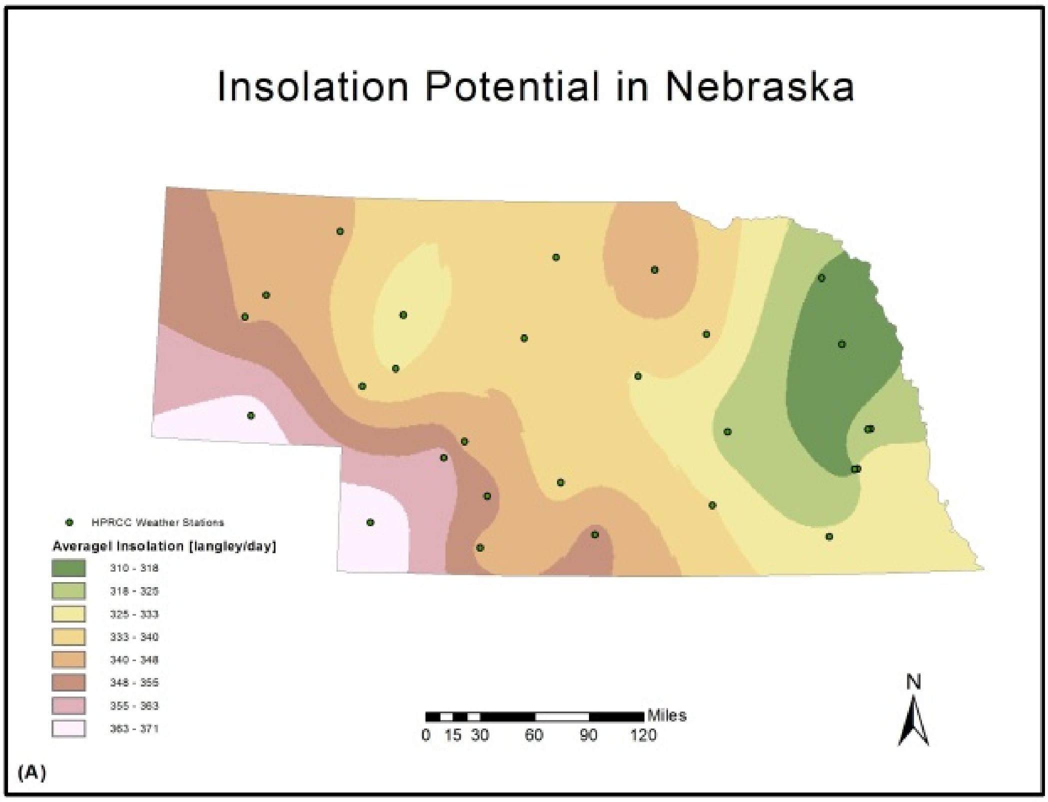
As for the software, ESRI's ArcGIS ver. 9.3.1 or later is used for this study. The department of Geography of University of Nebraska – Lincoln (UNL) provided free access to the software at the 24/7 computer laboratory at Hardin Hall. All the geospatial data are retrieved from public resources such as the Seamless Data Warehouse of U.S. Geological Survey (USGS).

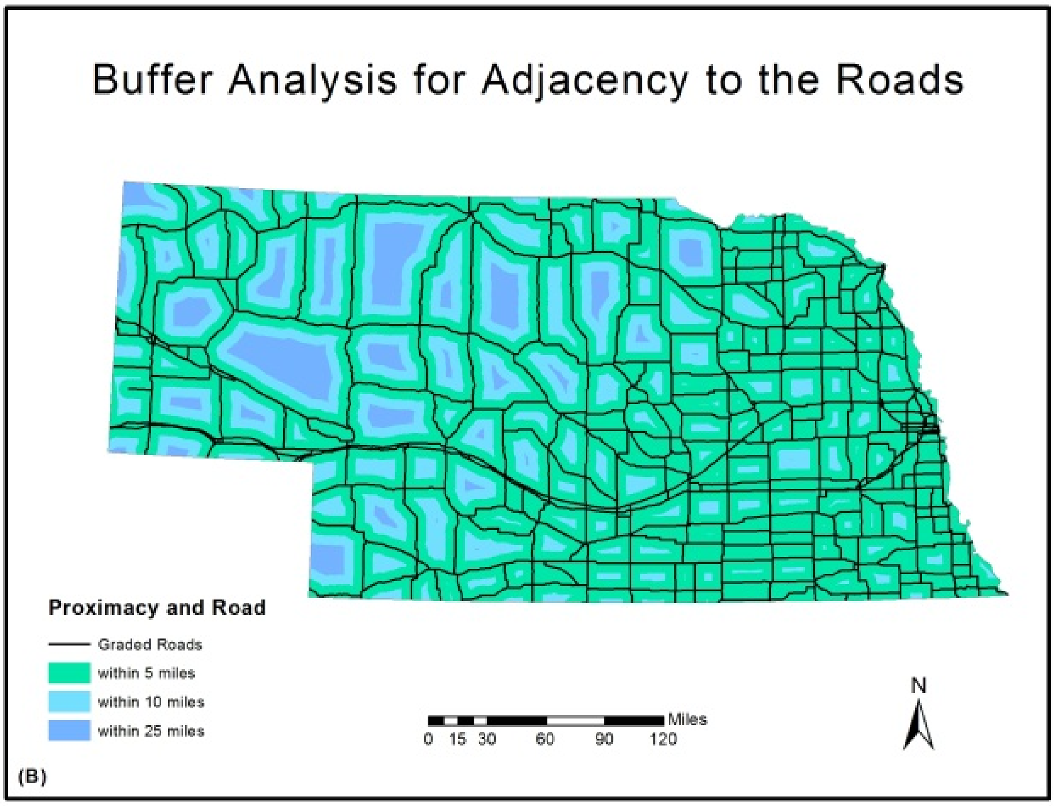
Federal Emergency Management Agency (FEMA) provides the map layer for transmission lines in the United States. However, because of the security concerns, the latest map is not provided to the public. The map layer, used in this study, is from 1993. More up-to-date data are needed for a better analysis of transmission lines.

Climate data, regarding insolation potential in mid-western U.S., are provided by HPRCC via its Classic Online Services. All the stations that have operated more than 20 years through December 31st, 2009 have been identified, and by averaging the 20 years of average annual insolation of each station, the insolation potential of the region is estimated.

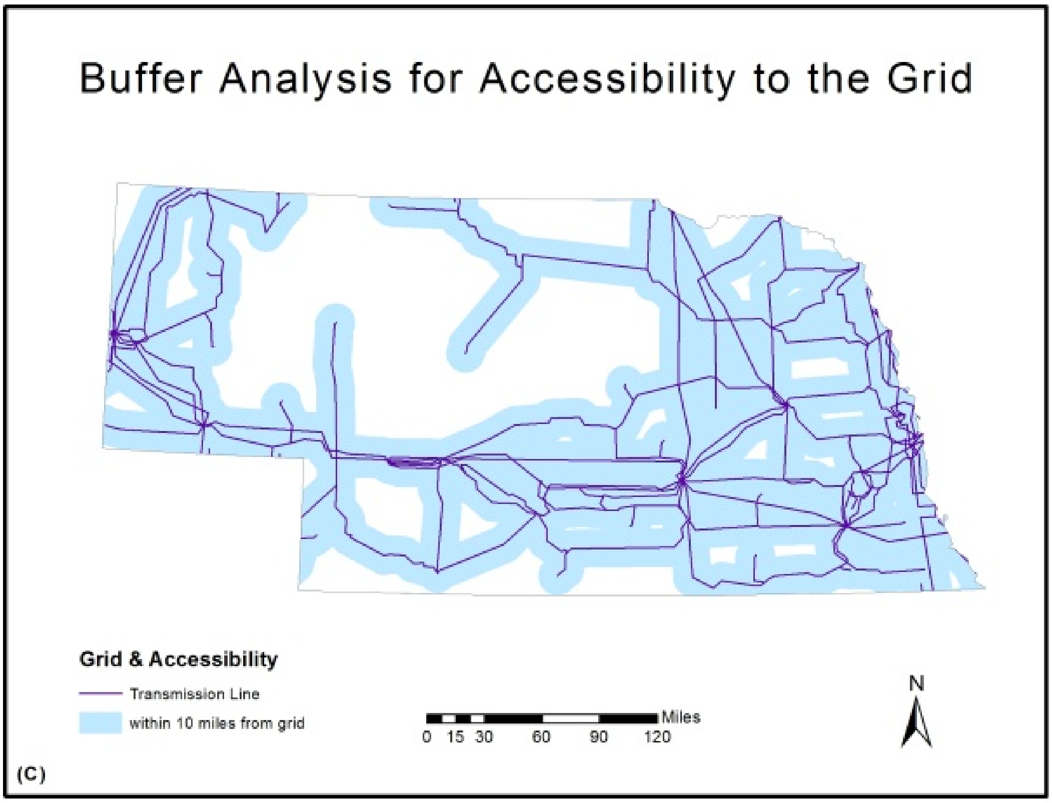
4. Results

Interpolation of the average daily insolation value at 28 HPRCC stations reveals the Northeast-to-Southwest pattern of insolation gradient in Nebraska (Figure 5A). The best insolation potential is found in Southwestern Nebraska, and therefore, the rest of the screening criteria mainly focus on Southwestern Nebraska. The buffer analysis for adjacency to the roads shows that every site in Nebraska falls within 25 miles of graded roads (Figure 5B). While the buffer analysis for accessibility to the grid show that the central and northern regions of Nebraska are not well covered, more than half of the southwestern region, where the most insolation potential is found, fall within 10 miles of transmission lines (Figure 5C). Topography of Southwestern Nebraska shows the region of horizontal sites as well as sloped sites (Figure 5D). After all the screening criteria of insolation potential, adjacency to the roads, accessibility to the grid, topography, and acreage are implemented, several sites are found to be optimal for grid-connected PV power plants (Figure 5E).

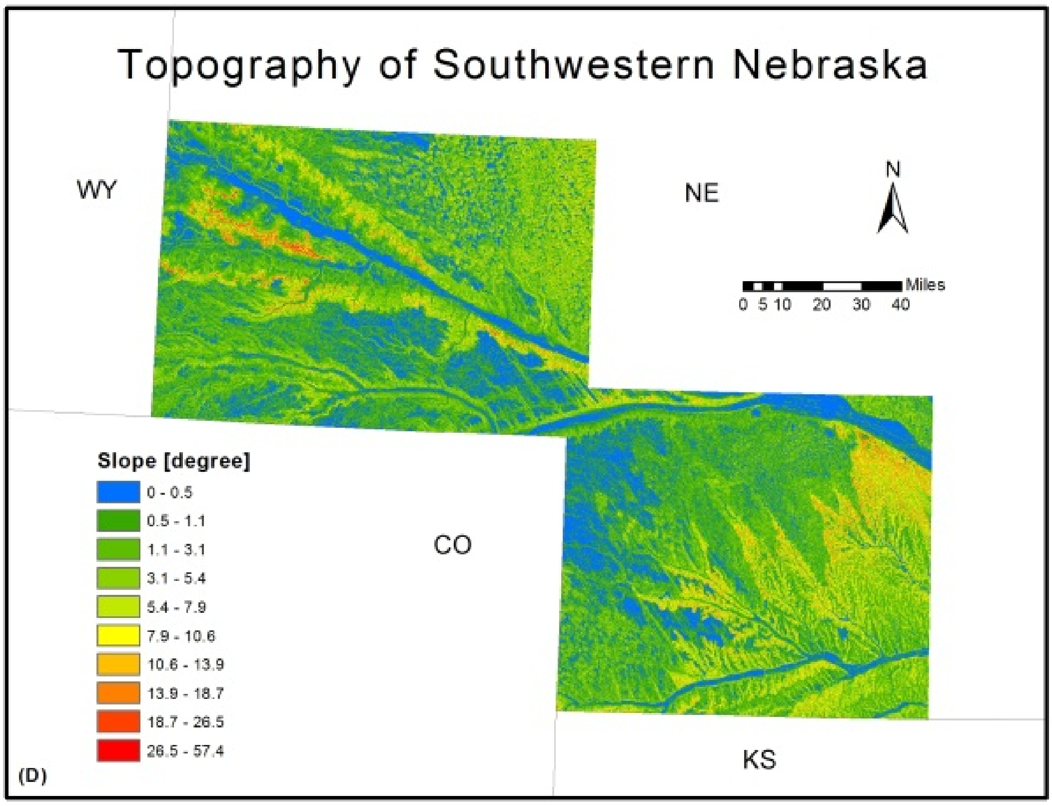




Buffer Analysis for Adjacency to the Roads
Proximacy and Road
Graded Roads
within 5 miles
within 10 miles
within 25 miles
Miles
0 15 30 60 90 120
N
(B)



Buffer Analysis for Accessibility to the Grid
Grid & Accessibility
Transmission Line
within 10 miles from grid
Miles
0 15 30 60 90 120
N
(C)



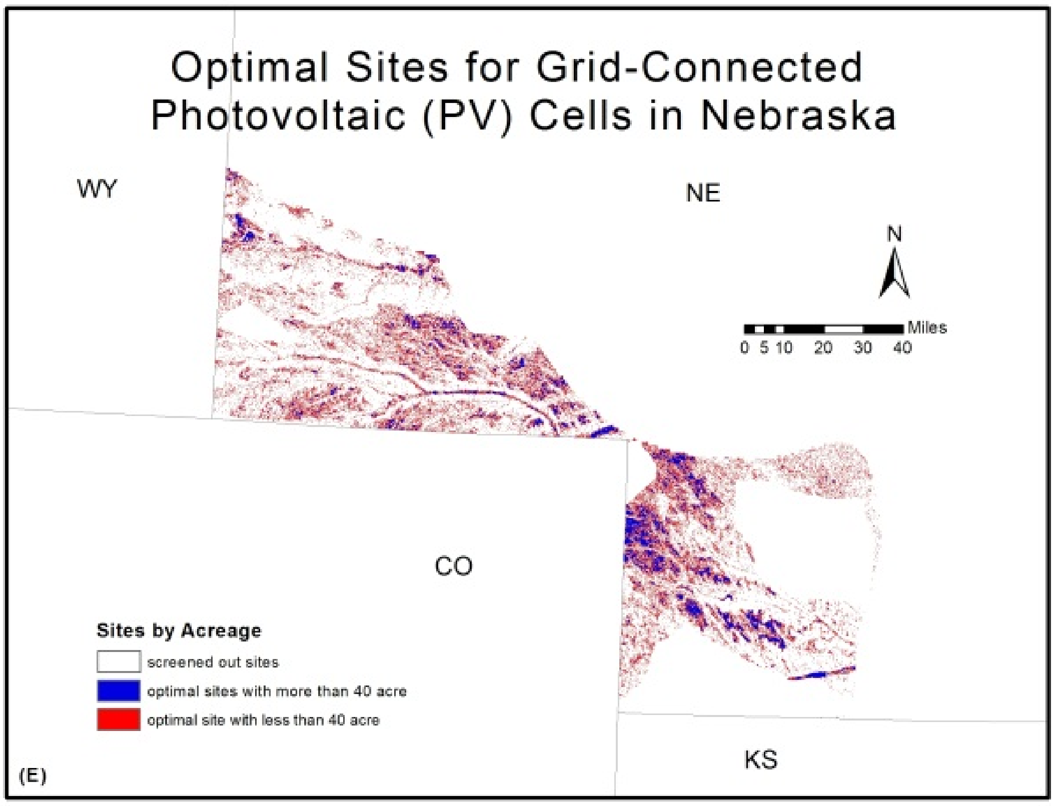


Figure 5A-E Each of the quantitative analysis and four qualitative analyses are mapped.

5. Discussion

According to the results of interpolation of insolation data, the maximum insolation intensity per day in Nebraska is approximately 370 [langley], which equates to 4.3 [kWh/m$^{2/}$day]. According to solar resource potential classification by National Renewable energy Laboratory (Table 2), it can be said that Nebraska does have a "Good" solar resource potential, although the state itself is ranked 13th nationally in terms of insolation potential.

kWh/m^2/day	Resource Potential
<4	Moderate
>4-5	Good
>5-6	Very Good
>6-7	Excellent

Table 2. Solar resource potential information established by National Renewable Energy Laboratory (NREL).

The interpolation also visually reveals the northeastern-to-southwestern gradient of insolation. On one hand, it is expected to have lower insolation potential at higher latitude, because of the latitudinal difference that results due to smaller noon sun angle. The east-to-west component of the gradient of insolation, on the other hand, is considered to be the result of meteorological influences. One explanation of this is that low pressure systems that often form around the state of Colorado (thus named "Colorado Low") potentially bring more moisture from the Gulf of Mexico to the east region of Nebraska than to the west because of its counterclockwise circulation of air mass. This produces more cloud cover and, therefore, reduces the amount of insolation received at the surface on the eastern side of

Nebraska. Another explanation is the cold air mass that comes from Alberta Canada. The cold air mass is stable, compact, and thus, associated with a high pressure system. This causes less cloud cover that blocks and reduces the insolation potential on the western side of Nebraska.

Figure 5B and 5C reveal that graded roads cover Nebraska, while transmission lines do not. Especially northern and central Nebraska lack transmission lines and it can be said that more solar energy can possibly be tapped by expanding and improving the network of transmission lines in central Nebraska.

By visually analyzing the satellite images (Figure 6), it is found that all the optimal sites estimated by this GIS study coincide with agricultural lands. This is a reasonable finding, considering the fact that the optimal sites for large-scale PV cell facilities are horizontal and abundant in sunlight making it also the optimal sites for the management of agriculture. Since this could potentially raise conflict over land between agriculture and solar energy, hybrid usage of agriculture and solar energy should be studied for more efficient use of land. For example, laying out a mosaic of solar panels and crops one after the other could potentially aim to reduce wind damage and erosion of the land while producing electricity at the same time.

Lakes are omitted from the analysis since it is simply not feasible to establish utility solar power plants there. Rivers and their floodplain are found to be coexistent with some agricultural land as well. However, the meander of the river means the land is being constantly transformed as well as the potential for possible flooding. Therefore, the land close to the meander and floodplain is not suitable for solar energy power plants that require the stability of the land for at least ten years.

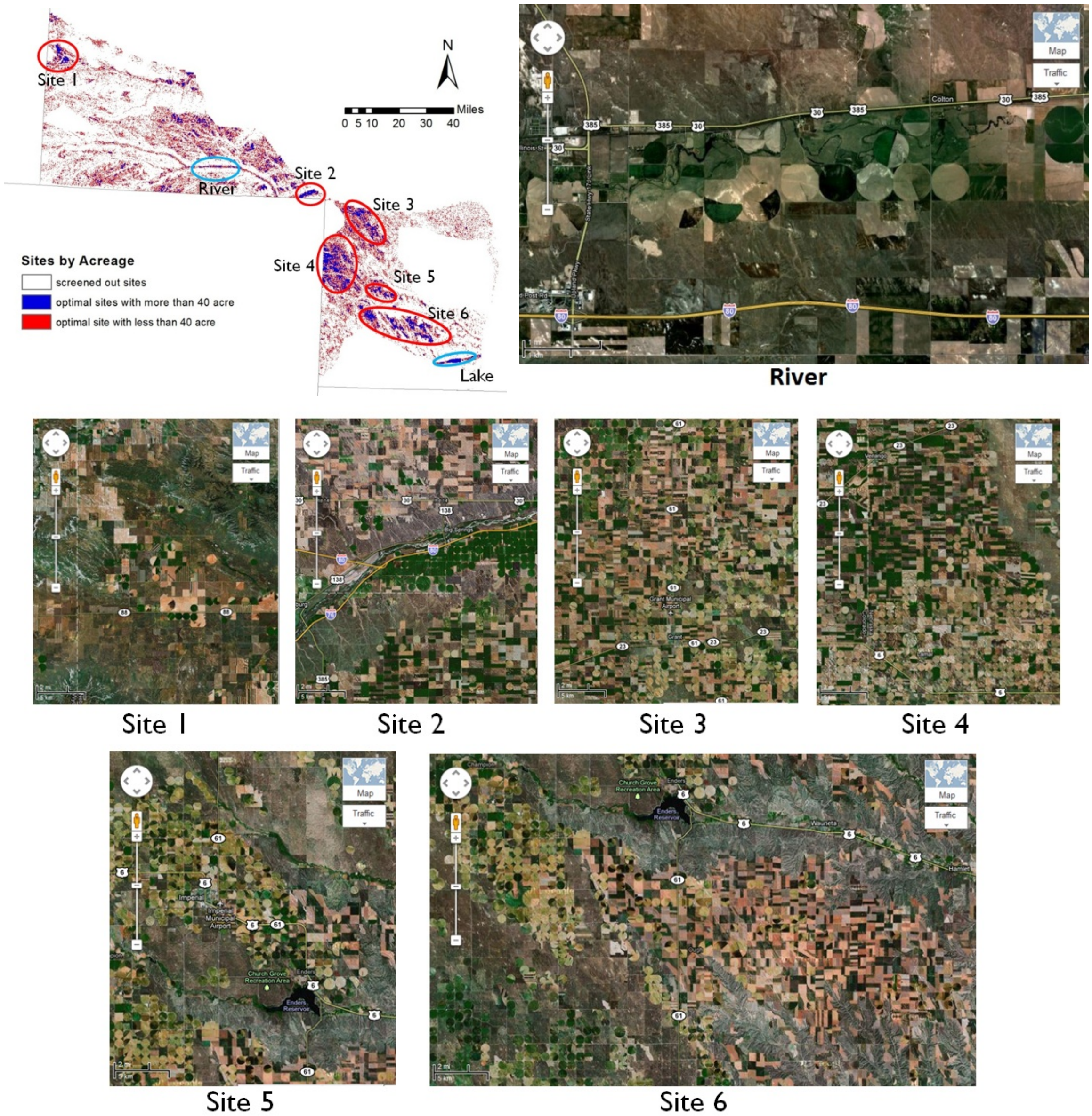


Figure 6 Total of 6 sites are identified as major candidate sites suitble for grid-connected utility solar power plants. Satellite images are retrieved from Google Maps in order to visually analize each site.

6. Conclusion

Estimating optimal sites for grid-connected utility solar power plants in Nebraska has an important significance in the context of development of renewable energies. There are various factors influencing the economic feasibility of PV cells, such as the efficiency of PV cells, the capacity of PV panels to follow the path of the sun, the cost of PV cells, institutional subsidies, insolation potential, accessibility to grid, and so on. In this paper, estimation and investigation of suitable sites for grid-connected PV cells were conducted using a GIS approach focusing on five non-PV-cell-function-oriented geographical factors. The five factors examined were insolation potential, road adjacency, accessibility to grid, topography, and acreage. It has been shown that:

(a) Weather is an important factor that controls the insolation potential through cloud cover that blocks sunlight. Although weather is largely influenced by global factors, there is a distinct difference in insolation potential within a state the size of Nebraska.

(b) Even in a mid-potential state like Nebraska, there exist sites with good insolation potential. Other states with insolation of mid potential should be studied more in detail as well for this reason.

(c) Possible hybrid usage of land between agriculture and PV power plants should be studied. All the optimal lands for PV power plants are agricultural land, and therefore, the possible conflict over land usage between solar energy and agriculture needs to be examined.

(d) For grid-connected PV cells, improved area coverage of transmission lines is more needed than that of graded roads in Nebraska. Graded roads cover all Nebraska, while transmission lines do not for the purpose of constructing PV power plants.

More work is needed for site-specific modeling and PV-panel-specific modeling with other non-geographical factors for further understanding the feasibility of solar energy in Nebraska. Temperature is an example of a panel-specific factor, which influences the conversion efficiency of different kinds of PV cells differently. Also, the relative distance between the optimal sites for PV cells and area of electricity consumption should be investigated to minimize the loss of electricity by transmission lines.

7. Reference

Environmental Protection Agency (EPA). 2010 "Data Guideline for Renewable Energy Generation potential on EPA and State Tracked Sites Maps Produced by EPA" Last updated: 17 September 2010. Accessed 13 December 2010 http://www.epa.gov/oswercpa/data.htm

Environmental Protection Agency (EPA). 2010 "Policy Driven and/or Utility Scale Photovoltaic (PV) Solar Energy Generation Potential Maps" Last updated: 27 September 2010. Accessed 13 December 2010 http://www.epa.gov/renewableenergyland/maps_utility_pv.htm

ESRI. 2008. "Boston Showcases Solar Power Potential with Web GIS." ArcNews Online. Accessed 6 March 2010 <http://www.esri.com/news/arcnews/fall08articles/boston-showcases.html>.

ESRI. 2009. "Mapping the Solar Potential of Rooftops" ArcNews Online. Accessed 6 March 2010 <http://www.esri.com/news/arcnews/fall09articles/mapping-the-solar.html>.

Johnson, George. 2009 "Plugging into the sun." National Geographic September 2009: 40-41.

High Plains Regional Cliate Center (HPRCC) Classic Online Services. Accessed 6 December 2010. http://www.hprcc.unl.edu/services/index.php?p=online

M. Vandenbergh, F.-P. Neirac and H. Turki. 1999 "A GIS approach for the siting of solar thermal power plants application to Tunisia." Journal de Physique.

Mehos, M. and B.Owens. 2005 "Siting Utility-Scale Concentrating Solar Power Projects." National Renewable Energy Laboratory. Accessed 10 March 2010 http://www.emnrd.state.nm.us/ecmd/Multimedia/documents/SitingCSP.pdf

Natural Resources Conservation Service (NRCS), United States Department of Agriculture. "Solar radiation unit conversions." Last update: 9 December 2010. Accessed 13 December 2010 http://www.wsi.nrcs.usda.gov/products/w2q/h&h/tools_models/agnps/info/SolarRadConversion.pdf

Nebraska Energy Office (NEO) 2010 “Comparison of Solar Power Potential by State” Last updated 11 March 2010. Accessed 13 Dec 2010.
http://www.neo.ne.gov/statshtml/201.htm

Osaka Gas, Personnel Department. Personal Interview at Boston Career Forum. 22 October 2010.

Ozaki Hiroyuki. 2009. “変容する太陽電池ビジネス(Changing Situation in the Business of Photovoltaic Cells)” 次世代環境ビジネス (Next-Generation Environmental Business). Tokyo: Nikkei Publishing Inc. p.120-129

Vajjhala, Shalini P. 2006 "Siting Renewable Energy Facilities: A Spatial analysis of Promises and Pitfalls." Resources for the Future. 6 March 2010
<http://www.rff.org/RFF/Documents/RFF-DP-06-34.pdf>